AUTISM SPEAKS – FINAL PROGRESS REPORT

Autism Speaks Grant# 7791 PI (Last, First) Atherton, Mark
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Grant Title Tuning Anxiety Out
Grant start date: 1 April 2012 Reporting period begin date: 1 April 2012
Grant end date: 30 June 2013 Reporting period end date: 30 June 2013

INSTRUCTIONS: Please insert your responses after each question. The space will expand to fit your entry.

This report is expected to cover the entire project. Please include pertinent information from previous years even if included in a prior report.

Results:

1. Please supply a lay summary of the overall project and its outcome. Please be brief and non-technical while still conveying the important relation to autism. Autism Speaks reserves the right to use this summary with the general public as needed.

Autism Speaks Trailblazer Awards are designed to support novel 'out of the box' research into aspects of autism. This award was granted to explore a potential tool for managing the disabling over-reaction to sound experienced by some people with autism.

Sensory problems are common in those affected by autism but are currently poorly understood. Many people with autism are reported to have over- and under-sensitivity to a number of different 'triggers' ranging across sight, sound and touch. Parents rate sensory problems as one of the top two areas of difficulty for family life. In this project the researchers explored whether new and emerging sound management technologies could be used to help adults with a diagnosis of autism spectrum disorder and abnormal sound sensitivity by attempting to filter out challenging sounds.

The researchers from Brunel and Cardiff Universities collected recordings of everyday sounds such as baby cries and machine noises that were commonly reported to be upsetting. These were played under test conditions to two groups of adults with autism who took part in the project: either at Cardiff University or at the Reading-based Kingwood Trust, a provider of services to adults with autism. Each individual was asked to rate the sounds on a computerised scale ranging from 'I like this sound' to 'I find this uncomfortable to listen to'. The levels of sound sensitivity of those taking part were also measured through questionnaires and recording of their Galvanic Skin Response, a physiological marker of stress.

The sounds were played firstly directly and then through an open non-electronic earpiece that filtered out a specific range of sound frequencies (the passive device); and lastly in a final set of simplified trials pure high frequency tones were played through an open electronic earpiece specifically developed by engineers at Brunel University that dynamically responded to and cancelled these peak sounds (the active device).

Although the numbers taking part were small and not all were able to go right through the trials process, the results show that the passive device reduced scores for the sounds found uncomfortable for many of the participants. The very small number of trials for the active device showed further reduced discomfort. The team concluded therefore that it is feasible both to identify the particular sounds that individuals with autism find challenging and to use sound management technologies to help people with autism and sound sensitivity to manage their sound environment.

At present sound technology found for example in smart phones and hearing aids only offers sound filtering rather than active noise cancellation but could be adapted for use by those with sound sensitivity relatively quickly and at relatively low cost. While the passive device offers a low-cost means of providing some relief to sound sensitivity the active device shows greater noise reduction potential but would need substantial further development.

The researchers hope that these encouraging results will lead on to further work that widens the exploration of sound sensitivity across the lifespan of people with autism and engages the producers of sound management technologies in developing solutions that specifically help people with autism.

2. In scientific terms, please state the aims of your grant as set forth in your grant application and what was accomplished to achieve these aims. Please limit your results to that which is directly related to the funded project.

(a) Establish through auditory testing what sounds individuals with autism each find challenging to determine the acoustic characteristics of these sounds and similarities and differences across the cohort:

It is highly desirable to find out why certain sounds are so much more unpleasant in Autism Spectrum Disorder (ASD); and more so, why sounds that are *not* considered unpleasant in Neurotypical participants (NTs) are considered so in the ASD population. The social and communicative problems in ASD also make it difficult to choose sounds due to the relatively small number of studies on this issue, so it was decided to rely on information from parents/participants and other anecdotal reports.

Given the paucity of data on which deconstructions of various sound frequencies are most troubling to the ASD population, we decided that the best approach was to use naturalistic sounds rather than simpler AM or FM modulations. Hopefully in future it will be possible to isolate specific troubling frequencies, but here our approach was to adhere to the principle that sound perception within the brain goes far beyond simple hair cell stimulation in the ear. The same goes for affective sounds and so using naturalistic, ethologically-valid sounds as a starting point in our explorations of this field seems justified.

Ten sounds were selected on the assumption that they are considered unpleasant in the ASD population, namely, Baby Crying, Electric Drill, Electric Shaver, Food Processor, Hairspray, Hand Saw, House Heater, Paper Shredder, Washing Machine, Wind Chimes. In addition, two further sounds were selected as expected to be experienced as pleasant or neutral, namely, Ambient Spring and Lake Sound, to explore participants' consistency in rating non-anxiogenic sounds. These sounds were downloaded from online sound file depositories freesound.org and soundjay.com. Audacity version 2.0.2 (http://audacity.sourceforge.net/) was used to edit each sound file down to 5s in duration, and resample sounds to 44.1 KHz resolution. In order to be comparable, all sound files were subsequently normalized to the same average volume level in the communication frequency range (0-4 kHz).

These ten sounds were played under test conditions to two groups of adults with autism who took part in the project either at Cardiff University or at the Reading-based Kingwood Trust, a provider of services to adults with autism. Each individual was asked to rate the sounds on a scale running *from* (rating of 10) *'I find this uncomfortable to listen to'* (rating of 0) *'I like this sound'*.

The levels of sound sensitivity of those taking part were also measured through questionnaires and recording of their Galvanic Skin Response, a physiological marker of stress attached to a wristband.

A noise sensitivity questionnaire was also sent to 50 families associated with the Kingwood Trust asking them to identify sounds that their family member with ASD liked and disliked. Midway through the project results had been received from 12 families identifying a broad range of sounds that caused the most distress, including percussive machine sounds, such as electric drills and sawing; human sounds e.g. baby crying, unexpected sounds, e.g. fire alarms; and social sounds, e.g. busy supermarkets. And all but one of the respondents identified music as a positive experience, seeking it out as part of their daily routine. This helped to confirm that appropriate sounds had been selected for testing.

Analysis of the trial results indicated that for the ASD participants based at Cardiff the most highly-rated unpleasant sound was Baby Crying, whilst Lake Sound was rated least unpleasant. For the ASD participants at Kingwood Electric Drill was rated the most unpleasant and Ambient Spring the least unpleasant. Table 1 gives a summary of sounds that were rated as most pleasant and unpleasant by the 16 participants in the study.

Table 1. Sounds rated as most pleasant and unpleasant

Sounds	% of participants
Unpleasant:	
Baby Crying	57
Electric Drill	25
Wind chimes	6
Hair Spray	6
Washing Machine	6
Pleasant:	
Spring Ambient	56
Wind chimes	31
Lake Sounds	13

(b) Test the effectiveness of noise reduction technologies in selectively attenuating the sounds that cohort members each find challenging to determine relevance to addressing autism sound sensitivity:

A Brunel passive (i.e. broadband, non-electronic) noise reduction device was configured (version “A”) to have its greatest noise reduction effect (generally over 30dB) above 4kHz, while within the ‘communication zone’ (0-4kHz), its noise reduction effect was limited to about 20dB. Each of the 12 selected sounds was also recorded through this passive device when fitted to an artificial ear (GRAS Type 43AG Ear and Cheek Simulator) to give a total of 24 sounds. For the majority of the sounds, across Cardiff and Kingwood groups, the sounds recorded through the Brunel passive noise reduction device were rated as being less unpleasant than the corresponding raw sound. This passive device significantly reduced displeasure for Baby Crying, Electric Drill, Electric Shaver, Hair Spray and Paper Shredder.

The ten sounds were played firstly directly and then through the Brunel passive device.

Subjective ratings for the passive device were compared with subjective ratings for a ‘placebo’ version. The ‘placebo’ was a similar device that had a noise reduction effect by virtue of physically occluding the ear but had no internal noise reduction features. Stimuli and condition presentation were counterbalanced and participants were blinded but this was not a double blind procedure.

Results showed a difference between passive device and ‘placebo’ for the unpleasant sounds. The sound through the passive device was rated as less uncomfortable than the rating for the ‘placebo’. Of 16 total participants (Cardiff and Kingwood), 13 gave a lower subjective rating to their most unpleasant sound, when they heard the sound through the real device compared with the placebo. For sounds that each had previously been identified as the most pleasant, the results showed that 6 gave a lower (more pleasant) rating, 7 gave an identical rating for both and 3 gave a higher rating for the placebo. See Table 2 for means and standards deviations.

Table 2. Subjective ratings of unpleasant and pleasant sounds (N=16)

Sounds	Placebo	Device	T Test		
	Mean (SD)	Mean (SD)	t	p	Cohen’s d
Unpleasant Sound	7.13 (2.29)	6.42 (2.28)	2.58	0.021	0.31
Pleasant Sound	1.22 (1.42)	1.06 (1.21)	1.71	NS	0.12

For the galvanic skin response measure, results were based on a much smaller sample set because data could not be collected for 6 participants due to testing difficulties. A further participant had outlying scores for 3 of the 4 conditions. The remaining small dataset of 9 prevents a clear conclusion. However, of these 9 participants, all had lower levels of response (indicating lower arousal level) when the sounds were played through the device than when played through the ‘placebo’. This applied to both the participants’ most unpleasant and most pleasant sounds (see Table 3).

Table 3. Galvanic skin response to unpleasant and pleasant sounds (N=9)

Sounds	Placebo	Device	T Test		
	Mean (SD)	Mean (SD)	t	p	Cohen’s d
Unpleasant Sound	3.63 (2.13)	3.18 (2.00)	3.73	0.006	0.22
Pleasant Sound	2.91 (2.02)	2.69 (1.92)	4.37	0.002	0.11

The results show feasibility of the procedure. The subjective ratings procedure enabled data to be collected for all participants and the GSR measure enabled data to be collected for the majority of participants. These results come from a very small dataset, and testing would be needed with a larger sample in which both participants and experimenter are blinded.

The results for both the subjective ratings (Table 2) and the galvanic skin responses (Table 3) show a trend in the expected direction, although the small dataset prevents further interpretation of the device effect. It is worth noting however, that the placebo device had a noise reduction effect of up to 20 dB reduction through partially occluding the ear and this itself may be sufficient compared to the greater noise reduction effect (up to 35 dB) of the real device.

Developing an active device (one using digital signal processing to dynamically target peak sounds) to work outside the lab proved to be problematical in the time available, which was anticipated by reviewers of the original project proposal. This was partially due to the complex characteristics of the battery of sounds chosen for the trials; and also the unfavourable acoustic conditions of the test environment (e.g. varying distance between patient and test sounds, different ear canal volumes) and the time available with the participants for testing. These factors combined to make algorithm convergence very difficult to obtain in practice, where the algorithm needed to converge on suitable parameter values in order to cancel a particular sound that could then change in real time. The portable active device built, while converging reliably in the artificial ear of the lab, did not remain converged for more than 2 or 3 seconds with participant testing conditions using a constant high frequency tone (3.5-6 kHz); which was insufficient time to collect ratings from the ASD participants. While these ASD participants commented on it being effective the results were not of sufficient statistical significance to analyse and report.

(c) Determine the feasibility of developing a portable and programmable noise reduction device – similar to an MP3 player – that can be widely used by adults (and potentially children) with autism:

Many noise reduction devices such as ear plugs and music earphones block or occlude the ear. Occluding the ear canal prevents the escape of conducted sounds, which makes one's own voice sound intensely loud and difficult to judge, which is what happens with conventional ear plugs. Thus an 'open' device that does not occlude the ear is desirable for comfort and quality of sound. The Brunel passive and active devices are open designs.

Commercial noise cancelling headphones, in the main, are intended for listening to music or for industrial use. They tend to be enclosed earmuff designs for noise frequencies below 1kHz. These relatively low frequencies are technically less demanding to treat, and happen to cover the range of much underlying interference noise (e.g. aircraft cabin hum). Commercial devices are found to be less effective in dealing with the more distressing high-frequency noises (e.g. from dental drills and other high-speed rotating machines). Commercially available devices also tend to occlude the ear (i.e. closed ear devices) and use Adaptive Filtering (AF), which performs noise reduction in the electrical domain, whereas true anti-noise in the acoustic domain (Active Noise Control or ANC) can enable open technology.

There are many smartphone 'apps' that claim to manage noise, we have evaluated several and they appear to fall into four categories:

(i) Noise monitor and alert: *'Noise Control'* by Y Lau (available iTunes store https://itunes.apple.com). Monitors and displays the environmental sound intensity on a bar graph, and automatically sounds a *"Shhh..."* when a predetermined level is exceeded. The Apps does not perform any noise reduction function.

(ii) Masker: *'SoundCurtain'* by FutureAcoustics (available iTunes store https://itunes.apple.com). Automatically adjusts the masking sound intensity, according to the environmental noise level – i.e. the masking sound is non-audibly quiet when the user environment is quiet. The user may preselect between a number of alternative masking sounds, according to personal preference and comfort. The App is rated positively in user reviews, and awarded "Best App for Creating Quiet Workspaces" in a Forbes review of top 10 iPhone Apps (Josh Clark, www.forbes.com, 10/07/2009).

(iii) Filter: *'iHearClearly'* by The Newport Avenue Group (available iTunes store https://itunes.apple.com). The user instigates the recording of a 'snippet' of environmental sound, which in the App is subsequently and continuously subtracted, in the electrical domain (AF equivalent) from the following listening sounds. The principle could work if the noise is constant and if the recording was made in the ear canal. However, these two conditions are rarely met in practical use, and the App store user reviews (on 14/05/2013) are universally very poor, with a score of 1, on a 1-5 scale.

(iv) Canceller: *'Noise Canceller'* by Haowen Ning (available https://play.google.com/store/apps/). The current App performs the same basic cancelling function, in the acoustic domain, as the Brunel ANC device. However, the tuning isn't automated and the user must adapt the cancellation effect by changing the signal phase and amplitude manually. Further, the system cancels all sounds, including desirable non-stationary speech sounds. Judging by comments from some of the 225 reviewers, the App works only at a single fixed setting and needs continuous manual adjustment, for even small movement in the distance between the user and the noise source – e.g. such as the user turning his head. App store user reviews (on 14/05/2013) rate the App lowly, with a low score of 1.7, on a 1-5 scale.

There is relatively little work involved in phone manufacturers and app developers enabling a noise reduction algorithm on a straightforward microphone to earphone line – i.e. to make the smartphone perform an Adaptive Filtering (AF) noise reduction. The possible medical context needs to be carefully considered here. Smartphone developers are most likely to develop such solutions when intended for generic consumer use. If specifically intended for ASD, then, technically, the smartphone could be classed as a medical device, and thus subject to a more bureaucratically demanding assessment regime (e.g. FDA approval in the US). The smartphone solution, implemented in current state-of-art, will have the general limitations of the AF system. It could be suitable for higher functioning persons, who can self-fit and control the application in potentially distressing, temporary noise situations. Currently available noise reduction app solutions are generally ineffective. However, smartphone technology incorporates appropriate signal processing hardware and already has sufficient computational power to perform a degree of ANC. Further, there appears to be sufficient activity, of sufficient variety, for something workable eventually emerging. A 16-tap fixed point filter, based on the current Brunel ANC binaural active device requires moderate computational power, and is within the capability of mid- to high-end smartphones. Smartphone internal hardware is, in principle, capable of receiving 3 microphone inputs (for binaural ANC). However, a search of available smartphones has failed to identify any where such 3 microphone lines are all ported to the external phone casing. Typically, the phone has just one external microphone port, for a mono headset, in addition to one fixed internal microphone. The wireless headset (e.g. Bluetooth) has become an established smartphone, and music player, accessory. The wireless headset can be designed with 2 microphones, to enable it perform the perception and actuation parts of mono-ANC, with the smartphone performing the more demanding digital signal processing part. A pair of such headsets could perform binaural ANC but would require development.

Hearing aid technology uses advanced AF-equivalent technology, combined with an almost open ear canal. Hearing aid electronics has evolved to reproduce near naturalness of sound. Furthermore, digital signal processing in hearing aids are well advanced in enhancing temporal and spectral resolution – i.e. to pull out speech, while suppressing non-speech (noise). ANC is of interest to hearing aid manufacturers, as a means for controlling feedback noise (whistling) in high amplification circuits, which are peak frequency (not dissimilar to the dental drill noise). Therefore if they can be persuaded of a commercial gain, it is within the technical capabilities of hearing aid manufacturers to develop an ASD specific noise reduction device (once it has been clearly defined what an adverse noise is in ASD), which is why it was not an explicit aim of the original project proposal to specifically investigate this technology. It is a question of whether the quantities involved make it commercially viable for hearing aid manufacturers to address ASD, or whether social responsibility is a sufficient motivation. Most audiology clinics will have experienced fitting a hearing aid to an autistic person, and it is an event that may stand out in the audiologist's memory. Hospitals in the UK in the main tender for single source hearing aid supply contracts. Thus the British Audiology Society, who have been presented with the current project (Atherton et. al., 2012), should be able to increase manufacturer interest. The manufacturer who can claim an ASD specific device in the market, improves their chance of winning a wider supply contract. There is also potential for widening the demand, for example, from motorsport drivers/spectators and other situations where intermittent loud noise is a problem while maintaining communication is important.

As people with ASD appear to seek out music as part of their daily routine, and music can mask unpleasant sounds, then the Brunel passive device version "B" offers potential improvement. Based on the trials, it appears that such a passive device coupled to a music player offers a low-cost, easy to distribute solution that some ASD people would value. However, the greater potential for active devices to target unpleasant dynamic sound characteristics up to about 8kHz is more attractive and there are two potential solutions within easy reach, namely: Development of noise reduction 'apps' for smartphones to incorporate available technology not obviously present in current solutions; and encouraging hearing aid manufacturers to target devices specifically at the ASD market using their current capabilities.

A further option is to develop a Brunel hybrid device that combines elements of the passive (broad band noise reduction above 6kHz) and active (targeting specific dynamic peak frequencies up to 6kHz) devices, which will require a research project of an estimated three-year duration.

(d) Encourage collaboration between researchers in non-autism fields who have skills that are relevant to autism intervention and those already interested and expert in autism who are seeking to translate this into practical day-to-day benefit for those affected:

Collaboration has been particularly successful in terms of:

(i) Mix and depth of expertise: The amicable collaboration of experienced investigators from disciplines that rarely collaborate was a distinct strength of the project, as it led to consideration of complex issues involving participant interaction with technology in the context of ASD. It was thus challenging for Brunel who had only previously tested the device on NT participants for dental drilling where the stimuli are more predictable and easily measured than may apply to adults with ASD; and for Cardiff in collaborating on technology development and engaging in treatment research.

(ii) Securing user buy-in to the project: As the scope of the research was ambitious in the time-scale allowed, access to participants from Cardiff and Kingwood Trust was vital so that the team could hit the ground running. This user-community buy-in was a distinct strength of the project even though engaging large numbers of participants turned out to be difficult. The pooling of participants across two sites was important in terms of increasing the available pool even though it was eventually necessary to seek further participants from the Cambridge Autism Research Centre.

3. Please discuss any problems encountered or unanticipated developments in the project since your mid-cycle report.

(a) Difficulty in recruiting participants was not envisaged by either us or the reviewers, which illustrates another practical lesson from this project. The Cardiff group had 7 ASD participants and the Kingwood group had only 4 full ASD participants. (Amongst the 7 ASD participants at Kingwood, 4 completed the entire test procedure, 3 were able to rate the sounds as delivered via headphones but did not want to wear the physical device and 1 was unable to tolerate the test procedure) and it is thus difficult to generalise findings to a wider population. Consequently from this short project conclusive answers regarding whether the technology will help all those on the autism spectrum cannot be delivered, which was anticipated by the reviewers.

(b) Complexity of the unpleasant sounds selected was inevitably greater than that previously tested for dental drill noise; many of the sounds tested had temporal character as well as frequency.

(c) Level of researcher input to the project given its ambitious nature was highlighted by most of the reviewers and proved to be an issue in that Brunel, Cardiff and Kingwood Trust put much more time into the project than was originally envisaged.

4. In hindsight, would you have structured this grant differently, and if so, how?

(a) Seek greater resource for participant recruitment and over subscribe the trials to allow for drop out.

(b) Build in more contingency to allow for participant no-shows.

5. Will you be continuing this line of research after your Autism Speaks grant has concluded? If so, what are the future plans for the project?

(a) The main focus of follow-on should be on recruitment and testing of ASD participants based at a research environment, as well as testing neurotypical (NT) participants to provide a control group for comparison.

(b) As a result of this project, Cardiff University has begun to explore sound sensitivity in students without ASD using the same research methodology in order to investigate whether sound sensitivity is or is not specific to ASD. This work could continue in parallel with further research in the ASD population effectively providing a control comparison for any wider ASD research.

(c) Continue research and development of a hybrid passive/active device to be stable in real-world environments.

6. Please comment on the impact this grant has had on your institution and your own research career and future directions?

(a) For Brunel:
(i) Stretched us out of the 'comfort zone' of lab device testing.
(ii) Highlighted the challenges of dealing with human participants and the difference between objective lab data versus human perception data.
(iii) Provided comparisons for our dental drill noise project.

(b) For Cardiff
(i) Has allowed us to be involved in the active development of an intervention technique, demonstrating the difficulties in attempting to go from 'bench to bedside' in technology development.
(ii) While we had suspected the heterogeneity of responses to sounds in the ASD population, we were surprised at the breadth of differences even across our small sample. This has strengthened our opinion that the sensory symptoms in ASD are still not understood, and require studies that go beyond mere 'between group' comparisons to appreciate the variability in the population.

Accomplishments:

1. Please list all other support solicited/received since your grant was made:
    a. List any funding solicited/received that utilized the data generated with this grant. Please include dollar amounts.
       Kingwood supported initial testing of NT participants.

    b. List any other relevant funding your lab solicited/received during this time period.
       N/A

2. Related activities (include publications, presentations, etc.):
    a. List all publications that are a result of this grant.
        1. Atherton et. al. Audiology conference, Nottingham, September 2012.
        2. Rotter et .al. REM conference, Paris, November 2012.

    b. List any major presentations that are a result of this grant
        N/A

    c. List any other relevant publications and presentations made by your lab during this time period.
        Cardiff Methods Report.
        Brunel Technology Report.

3. Please list relevant honors and awards. You may also include any <u>major</u> lay press/publicity you received by undertaking this project (magazine profiles; TV interviews etc)
    N/A

We understand that publications/further funding may result even several years after the grant period. Nonetheless, it is for the continuation of Autism Speaks' programs that we ask all grantees, regardless of grant status, to update us on any publications and additional funding secured as a result of this Autism Speaks grant.

Please also note that you must comply with the Autism Speaks' Public Access policy. Requirements and instructions are available at: http://www.autismspeaks.org/science/policy-statements/policy-public-access-research-we-fund

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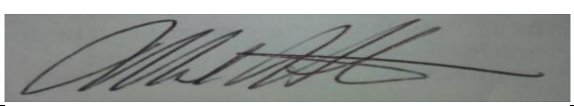
PRINCIPAL INVESTIGATOR ASSURANCE: By submitting this completed report form, I certify that the statements herein are true, and accurate to the best of my knowledge. I am aware that any false, fictitious or fraudulent claims may subject me to criminal, civil or administrative penalties. I agree to accept scientific responsibility for the scientific conduct of the project and provide a final progress and financial report no later than sixty (60) days after the grant end date per Autism Speaks' terms and conditions.

Principal Investigator Signature:  Date: 19 July 2013